Can LiDAR Point Clouds effectively contribute to Safer Apron Operations?
- Results of an experimental controller-in-the-loop study -

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Agenda

• Introduction to LiDAR sensing for Apron Surveillance
• Background to the experimental CITL Study
• Experimental Design
• Experimental Setup
• Experimental Results
• Conclusion & Outlook
The Need for Risk Mitigation

- future aviation and ATM concepts call for improved safety targets (e.g. SESAR, ICAO GANP)
- the contribution of **airport surface operations** to risks is substantial (injuries to human health and damage to material)
- areas affected by surface operations:
  - manoeuvring area
  - **apron**

**Source:** Boeing StatSum

**Introduction to LiDAR sensing for Apron Surveillance**

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The Apron – Is there a Safety Problem?

- common problem: incomplete/not publicly accessible reporting of safety relevant occurrences on the apron
- available statistics indicate the **apron to account for a significant share of the total risk** in aviation:
  - probability of apron personnel at US airports to be fatally/severely injured: 0.47×10E-6 per aircraft departure [NTSB]
  - 5 of 41 recorded ground occurrences at Australian airports FOD-related [ATSB]
  - US fatal accident rate during pushback: 2.12×10E-8 [NTSB, AIDS, ATADS]
  - ≈ $6.8 million total costs of material damage resulting from ground handling accidents [Global Aviation Safety Network]

Sources: airdisaster.com, aviationpics.de

Distribution of Australian Ground occurrences by location (except from the RWY)

Risk Mitigation by LiDAR-based Surveillance

Overarching Risk Assessment

- identify and mitigate the risk of incidents and accidents on the airport apron
- by improving the **Situational Awareness** of the responsible controller
- through the provision of processed **LiDAR 3D point data**.
- Eurocontrol SAM used as methodological framework

<table>
<thead>
<tr>
<th>Basic Functions</th>
<th>Relevant Target Objects</th>
<th>State of Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection</td>
<td>All objects that are not part of the static apron scenery</td>
<td>stationary &amp; in motion</td>
</tr>
<tr>
<td>Classification</td>
<td>Aircraft (AC), ground vehicles (GV), pedestrians (PED), turnaround equipment (EQ), FOD</td>
<td>stationary &amp; in motion</td>
</tr>
<tr>
<td>Instance Recognition</td>
<td>AC: e.g. Airbus 319-100, Boeing 737-700; GV: e.g. follow me, fuel truck</td>
<td>stationary &amp; in motion</td>
</tr>
<tr>
<td>Tracking</td>
<td>All objects from line &quot;Classification&quot;, all object types from line &quot;Instance Recognition&quot;</td>
<td>in motion</td>
</tr>
</tbody>
</table>

LiDAR-based concept for apron surveillance, see ["LiDAR Performance Requirements and Optimized Sensor Positioning for Point Cloud-based Risk Mitigation at Airport Aprons", ICRAT 2014]
A particular challenge: Processing LiDAR 3D Point Data

LiDAR Neptec OPAL 360 at Dresden airport

Source: Google Earth, 2015
Processing (I) - Object Detection Technique

- The developed detection technique is fully functional and real-time capable.
- Detection performance quantified for several test objects and environmental conditions within several field trials, see ["Performance Evaluation of LiDAR Point Clouds towards Automated FOD Detection on Airport Apron", ATACCS 2015]
Processing (II) - Object Classification Technique

✓ the developed classification technique has successfully undergone a proof of concept study, see ["Introducing LiDAR Point Cloud-based Object Classification towards Safer Apron Operations", ESAVS 2016]

○ but is still of restricted functionality (missing real-time capability, limited number of aircraft models etc.)

Left: A319-100 Right: B737-700

Green Box: Estimated position
Blue Box: True position

Measurement quality (static aircraft)

<table>
<thead>
<tr>
<th>Aircraft type</th>
<th>Angular Error</th>
<th>Translational Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>A319-100</td>
<td>1.159°</td>
<td>0.868m</td>
</tr>
<tr>
<td>B737-700</td>
<td>3.701°</td>
<td>0.534m</td>
</tr>
</tbody>
</table>

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Methodological Background to this CITL Study

- Recently performed Risk Assessment on apron safety
  - hazard & cause analyses conducted
  - risk mitigation concept based on LiDAR sensing developed, among others:
    - LiDAR 3D point data processing (in progress!)
    - data visualization concept for apron controller working position (CWP)

  - **Open Issue: Concept evaluation**
    - central research question: "If and to what extent a LiDAR support at the apron CWP will reduce risks for apron operations?"
    - method: experimental controller-in-the-loop (CITL) study to evaluate selected metrics representing the achieved safety level
Experimental Design (I)

- **control condition:** Common Apron CWP → Configuration 1
- **experimental conditions:** LiDAR Apron CWP with
  - Performance Level “Real Time” → Configuration 2
  - Performance Level “Case Study” → Configuration 3
- **test persons:** 18 subjects, two groups

<table>
<thead>
<tr>
<th>Control Condition</th>
<th>Experimental Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>group 1</td>
<td>Configuration 1</td>
</tr>
<tr>
<td>group 2</td>
<td>Configuration 2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance Level</th>
<th>Time Delay Detection</th>
<th>Time Delay Classification</th>
<th>Time Delay Tracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real Time</td>
<td>All objects: 0.5s</td>
<td>All objects: 0.5s</td>
<td>All objects: 0.5s</td>
</tr>
<tr>
<td>Case Study</td>
<td>AC: 2s</td>
<td>AC: 2s</td>
<td>No tracking</td>
</tr>
<tr>
<td></td>
<td>GV/EQ: 10s</td>
<td>GV/EQ: 10s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PED: 25s</td>
<td>PED: 25s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FOD: 50s</td>
<td>FOD: 50s</td>
<td></td>
</tr>
</tbody>
</table>

**Groups of subjects**

**Definition of LiDAR performance levels**

AC = Aircraft     GV = Ground Vehicle     EQ = Equipment
PED = Pedestrian   FOD = Foreign Object Debris
Experimental Design (II)

• subjects’ tasks within the apron boundaries
  • issuing clearances for aircraft and ground vehicles
  • recognition and reporting of emerging or already present hazardous situations
  
• ...for a total of 21 scenarios
  • 4 standard scenarios
  • 17 hazard scenarios:
    • ultimately result in hazardous situations
    • contain cause and hazard indicators (visual cues)

• ...under different environmental conditions (CAVOK, CAT IIIa etc.)

• dependent variables:
  • primary variables: Hazard Recognition Rate, Reaction times
  • secondary variables: Situational awareness, workload, camera usage intensity
Experimental Setup

Experimental CWP at TU Dresden

LiDAR GUI at the experimental CWP

Keyboard Layout of experimental CWP

LiDAR GUI icons representing all potential target objects
Results for the primary dependent variables

<table>
<thead>
<tr>
<th></th>
<th>Default Apron CWP (config. 1)</th>
<th>LiDAR Apron CWP with “Real Time” (config. 2)</th>
<th>LiDAR Apron CWP with “Case Study” (config. 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of recognized hazards (max. 17)</td>
<td>µ = 13.9, σ = 1.65</td>
<td>µ = 16.8, σ = 0.42</td>
<td>µ = 14.9, σ = 1.85</td>
</tr>
<tr>
<td>Hazard Recognition Rate (HRR) [%]</td>
<td>81%</td>
<td>99%</td>
<td>88%</td>
</tr>
</tbody>
</table>

- significantly increased HRRs for both LiDAR configurations
- analysis by hazard groups: Highest HRR in FOD recognition for both LiDAR configurations (+33% “Real Time”, +24% “Case Study”)
Results for the primary dependent variables

- Lowest RTHR for LiDAR configuration 2 “Real Time” ($\mu=19s$)
- Increased RTHR for LiDAR configuration 3 “Case Study” ($\mu=38s$) compared to “Default Apron CWP” ($\mu=34s$)
Results for the secondary dependent variables

Situational awareness
(SART scale: -14 is lowest, +46 is highest)

Workload
(ISA scale: 1 is highest, 5 is lowest)

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<tbody>
<tr>
<td>SA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WL µ</td>
<td>3.6</td>
<td>4.1</td>
<td>3.7</td>
</tr>
<tr>
<td>WL σ</td>
<td>0.5</td>
<td>0.4</td>
<td>0.6</td>
</tr>
</tbody>
</table>

- LiDAR config. 2 “Real Time” with positive contributions on the subjects’ Situational awareness and Workload
- LiDAR config. 3 “Case Study” with marginal improvements compared to config. 1 “Default Apron CWP”

- LiDAR config. 2 “Real Time” with 75% less camera changes and motions compared to config. 1 “Default Apron CWP”
- LiDAR config. 3 “Case Study” with a smaller reduction (-24%) compared to config. 1 “Default Apron CWP”
Summary & Outlook

Achievements

☑ the tested LiDAR system (both configurations) resulted in an enhanced apron controller’s capability to recognize hazards
☑ situational awareness and workload also tend to improve
☑ the benefits are highest for the LiDAR performance level “Real Time”

Next steps

• field trial of our LiDAR system at Dresden airport
• further development of the data processing techniques
• extension of the current LiDAR GUI by automated surveillance functions
• planning and undertaking of a 2nd experimental study with
  • new configurations based on a higher level of automation
  • adjustments for the experimental design and setup (“lessons learned” from the previous study)
Questions – opinions – suggestions?

Thank you.

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